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The XM561 Cargo Truck — A Breakthrough in Mobility

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THE PURPOSE OF THIS PAPER is to outline the approach to the development of the "Truck, Cargo, 1-1/4 Ton, 6x6, XM561," with specific emphasis on the Army's objectives. A description of the concept development, XM561 design configuration, articulation system, and mobility evaluation comprise a major portion of this paper. Also discussed and of prime importance to the Army are the durability and reliability, ease of maintenance, logistics and human engineering factors taken into consideration.

HISTORY OR BACKGROUND

In the past, the Army has relied on normal advancements in the state-of-the-art within the civilian automotive industry for application to military vehicle design.

The belief that the development of military vehicles compatible with the Army's requirements can be achieved in this manner is no longer sound, due principally to the significant difference which exists in the military environment and the general feeling that, in the future, the opportunities to use highways and secondary roads will become less frequent, thus requiring more versatility and ruggedness in the military vehicle.

The current operational military fleet includes trucks of 1/4, 3/4, 2-1/2, 5, and 10 ton rated capacity. The design of these vehicles was established over 10 years ago, with some representing only improvements over World War II vehicles. In one instance, for the 1/4 ton truck, a new design (M151, 1/4 ton truck) entered service in 1961. Also, with the recent emphasis placed on the need for a multifuel capability of military transport truck engines, the current 2-1/2 and 5 ton versions have been released for production incorporating these new powerplants. Including these vehicles, however, all are conventional design military transport trucks representing significant advances over their predecessors, but not providing the degree of response to current objectives now deemed essential in future vehicles.

The general objectivies of the current development include the following:

1. Reduction of types and sizes of vehicles to the maximum extent feasible, with each having an optimum cargo area.
2. Reduction of line items of repair parts support requirements.
3. Reduction of fuel requirements.
4. Provision of rapid loading and unloading.
5. Design to facilitate maintenance in the field.
6. Reduction of weight and bulk without compromising reliability and durability.
7. Increase in standardization and interchangeability of parts.

It is further required that the new vehicles show the following:

1. Significant improvement in cross country mobility, including an inherent swimming capability.
2. Improvement in fuel consumption.
3. Improvement in durability and reliability.
4. Ease of maintenance, including reduction in maintenance time.
5. Minimum vehicle weight, but not at the expense of durability and reliability.
6. Air transportability, including airdrop.

ABSTRACT

A new concept in wheeled vehicle mobility is presented which verifies the advantage of an articulated system over the rigid wheeled vehicle. This paper traces the history of the development of the XM561 cargo truck, and presents the design configuration, articulation system, and mobility evaluation as compared with other military vehicles.

The 1/4 ton truck task was established in June 1961, and the military characteristics for "Truck, Utility, High Mobility, Light Duty XM561" were formally approved in December 1961.

At about this time, R. R. Gamaunt, an independent inventor, recognized the limitations of the conventional wheeled vehicle, both civilian and off-road. After an extensive 12 year mobility study, Gamaunt preceeded to design a vehicle for use in fighting forest fires. On completion, the design showed great possibilities not only for fire fighting, but also for military use.

As a result, during the spring of 1959, Gamaunt approached Ling-Temco-Vought with a unique vehicle concept which promised significant improvement in wheeled vehicle performance. This company agreed to the design and fabrication of a vehicle, using standard automotive components, for evaluation of the new concept. A program was initiated to test the concept, determine the capabilities of the vehicle, and to present the results, if satisfactory, to cognizant military Commands.

On Sept. 30, 1960, the concept vehicle was completed at the Ling-Temco-Vought facility in Dallas, Texas (Fig. 1). During preliminary shakedown on prepared surfaces, the vehicle was dynamically stable in cornering and during brake tests at all road speeds. Riding qualities were superior to standard military trucks through the 5 ton range. All handling characteristics were equivalent to commercial trucks of comparable weight class.

First phase tests started on flat, cross country terrain and later included plowed fields. The payload was gradually increased up to full rated load, and vehicle speeds were increased, reaching maximum severity at 25 mph on plowed fields at design gross vehicle weight (5650 lb).

Cross country tests were conducted in an extremely severe environment consisting of natural swamps, water, mud, ditches,

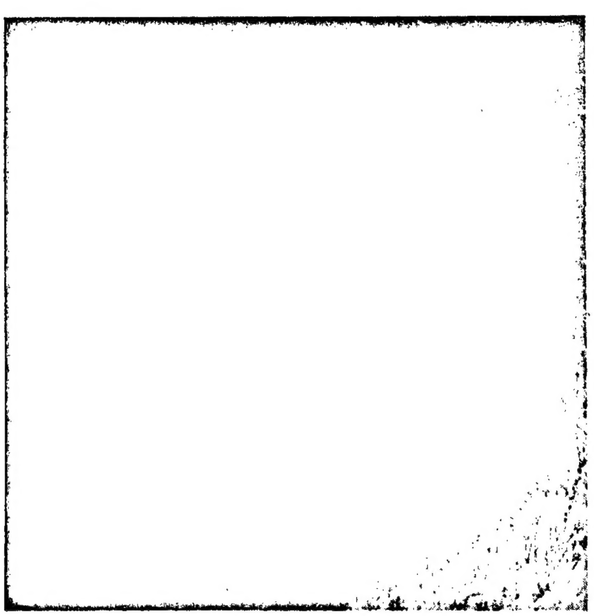

Fig. 1 - Gama Goat concept vehicle

washouts, brush, trees, and slopes up to 60%. The operations continued at full gross vehicle weight on this course during November and December, confirming the earlier indication of dynamic stability and ease of handling. In addition, these tests clearly demonstrated the superior mobility of the vehicle.

The articulated design permitted nearly constant wheel loading and corresponding low ground pressure on all tires even when stumps, logs, and debris were encountered beneath the soft soils. On firm soil, the articulated wheels readily followed severe changes in contour, providing all wheel traction under the most adverse terrain conditions.

At the end of December 1960, the tests were completed with the following results:

1. The vehicle concept was functionally satisfactory using standard automotive components.

2. The concept maintained the desirable handling and ride characteristics of a vehicle intended for highway operations.

3. It was capable of airlift and air transport.

4. It was highly maneuverable while crossing inland lakes and waterways.

5. Superior mobility was obvious in all cross country operations.

Beginning in January 1961, the vehicle made demonstrations at seven military bases in the continental United States. as well as four Commands in Europe. In all, a total of 10,000 miles was accumulated in a military environment, during testing and demonstrating.

During this demonstration program, Ling-Temco-Vought initiated an active design effort toward a new 1-1/4 ton vehicle which was to incorporate recommendations received from military observers. The approach to accomplish this objective was as follows:

1. The design would retain the basic features of the concept vehicle.

2. Mobility would be comparable to, or exceed the mobility of the concept vehicle.

3. The design would incorporate the utility, reliability, and endurance requirements desired by the Army.

The design was completed in January 1962, and long lead time hardware problems were resolved. In February 1962, Ling-Temco-Vought proposed their design in response to the Government's Request for Proposal on a new 1-1/4 ton cargo truck (XM561). In March 1963, Ling-Temco-Vought was awarded a contract for the design, development, and fabrication of two test rigs and 12 prototype vehicles. The test rigs have been subjected to extensive engineering design tests since January 1964.

DESIGN CHARACTERISTICS

The XM561 design is based on the carrier-tractor concept of its predecessor with an identical articulation system. It is a general purpose vehicle to be utilized by the logistical and tactical elements of the Army as a carrier for cargo and personnel, as a firing platform for weapons and carrier

for other weapons, as a front line ambulance, as well as a field ambulance, and as a prime mover for towed loads.

The overall utility of the XM561, based on the unusual number of military requirements or uses dictated its configuration. As shown in Fig. 2, the vehicle is 84 in. wide and 221.5 in. long. The cargo area is approximately 50 sq ft. The distance between the wheels wells in the carrier is 52 in. to accommodate two standard pallets. The carrier length was established at 92-5/8 in. to accommodate standard NATO litters for ambulance versions. The carrier is capable of transporting eight combat equipped troops, in addition to the driver and co-driver in the tractor.

To achieve light weight, both the tractor and carrier are aluminum and utilize the concepts of integrated body construction. Other components will contain as much aluminum as is considered practical for military use. The vehicle can be airdropped with full 2500 lb payload, or air delivery in Phase I of airborne operations.

Fig. 3 is a three-dimensional layout of the XM561. This view shows the installation of the General Motors GM-3-53 engine. This engine and the aircooled Lycoming AVM-310 engine are both under Government test and evaluation. The GM-3-53 engine is rated at 103 gross hp at 2800 rpm and delivers 215 ft-lb torque at 1500 rpm. The Lycoming engine is of higher capacity and is downrated to the approximate GM-3-53 rating for installation in the XM561. The GM-3-53 engine is capable of operation on diesel and CIE fuels, whereas the AVM-310 has a multifuel capability. The engine compartment (rear of the tractor) is dry.

Both the front and rear wheels of the vehicle steer by means of a conventional Ackermann system. Torsional output from the steering wheel is transmitted directly into both front and rear 24/1 gearboxes. Vehicle turning radius is established at 29 ft. The rear wheels understeer approximately 50%.

The XM561 has independent suspension on all six wheels. The front and rear axles use the conventional "A" arms and coil springs for suspension. The center axle is a swing axle design using a single leaf transverse spring. This design was resorted to in the center axle for the purpose of weight and cost reduction. The center axle is mounted on trunions at fore and aft locations on the tractor, thus allowing a pivoting of this axle about the driveline axis of ± 15 deg.

Wheel rates were designed at 272 lb/in. on the front

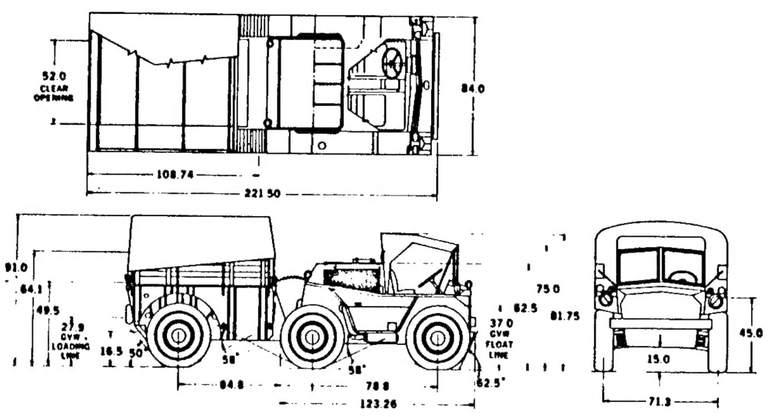

Fig. 2 - General configuration of XM561

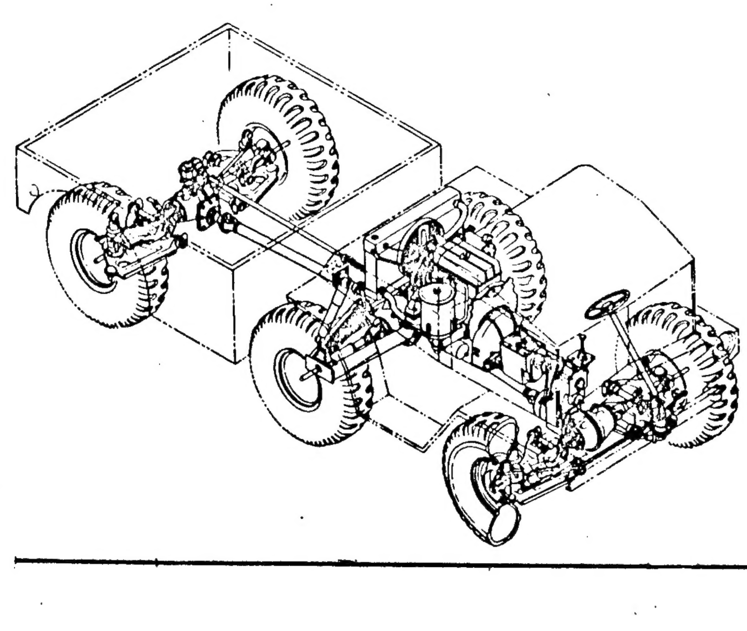

Fig. 3 - Three-dimensional layout of XM561

wheels, 282 lb/in. on the center wheels, and 340 lb/in. on the rear wheels.

All differentials have positive traction and are set to slip at approximately 400 ft-lb axle torque. Axle ratios are 5.57: 1.

The vehicle is equipped with a four-speed commercial transmission and a two-speed transfer case. Drive may be selected for two (center axle only) or six-wheel drive and high or low transfer. Low transfer is employed in six-wheel drive only.

The XM561 tires are 11.00 x 18, four-ply rated, and tubeless. Within certain limitations in overall vehicle design, configuration, and availability, the tire size was selected as being optimum for soft soil performance. Although steel wheels are standard, aluminum wheels will be subjected to test and evaluation. Pending the outcome of these tests and further cost/weight comparison, a positive selection on material will be made for production vehicles.

The performance of the XM561 has proven to be exceptional. It has a top speed of 60 mph on the highway, and a swimming speed (using only the wheels for propulsion) of 2 mph (Fig. 4). It can climb a 60% slope and negotiate a 26 in. step. Maximum tractive effort has been measured at 8300 lb.

Gross vehicle weight is 8960 lb, including a 2500 lb payload and a 400 lb crew allowance. Weight distribution is as follows: front axle - 2424 lb; center axle - 3255 lb; and rear axle - 3281 lb.

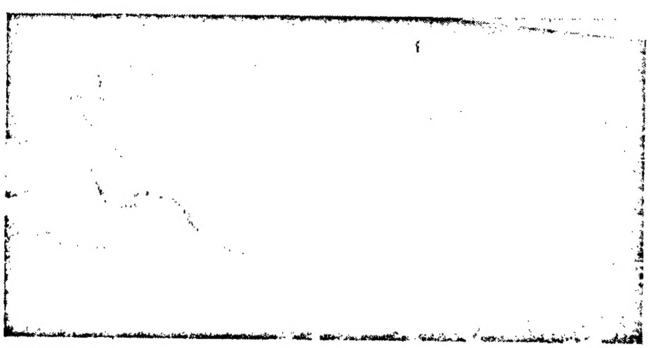

Fig. 4 - XM561 swimming

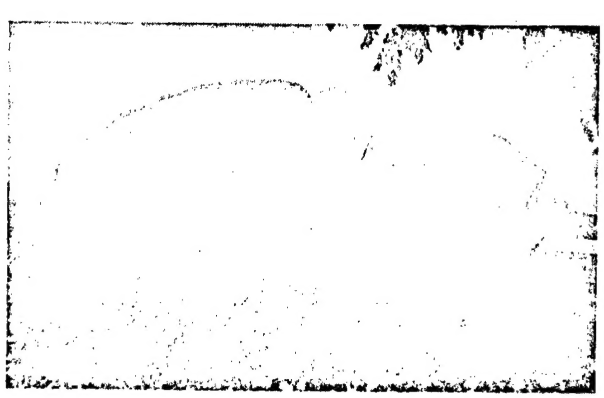

Fig. 5 - XM561 land operation

Fig. 5 shows the XM561 prototype vehicle which is now being subjected to Government test and evaluation.

Durability and reliability are significant factors in the design of a military vehicle and they have been stressed throughout the design of the XM561. The specification requirements imposed have virtually mandated the construction of a durable vehicle. What might be considered a bonus feature of the articulated design is that torsional body stresses are negligible, thereby effectively reducing proneness to body failures (very important for a swimming vehicle) and secondary causes resulting from torsional body deflections.

Extensive attention has been given to the design of durable components. Redesign, whenever necessary, has been applied in areas where durability and reliability were found to be marginal.

ARTICULATION SYSTEM

The XM561 articulation system, which is the principal design feature responsible for its unique mobility characteristics over adverse terrain, is composed of four basic components: the carrier casting, the "A" frame, the front carrier support casting, and the tractor hitch casting. Fig. 6 shows these individual parts and their arrangement as an assembly. The casting mounted on the carrier receives the "A" frame casting supported by a combined thrust radial bearing. This in turn is supported by a bulkhead casting which serves as the bearing at the forward end of the carrier. The "A" frame is attached to the tractor casting through two pin connections at either side of this casting.

The arrangement herein described allows the carrier to pitch ±40 deg with respect to the tractor, and to rotate about the driveline axis ±30 deg; bump stops on the "A" frame limit the roll to this value. Similar stops are provided at the rear of the tractor and front of the carrier to limit the pitch angle. These particular degrees of freedom, coupled with the ability of the center axle to rotate ±15 deg allow the vehicle to maintain uniform ground contact over vir-

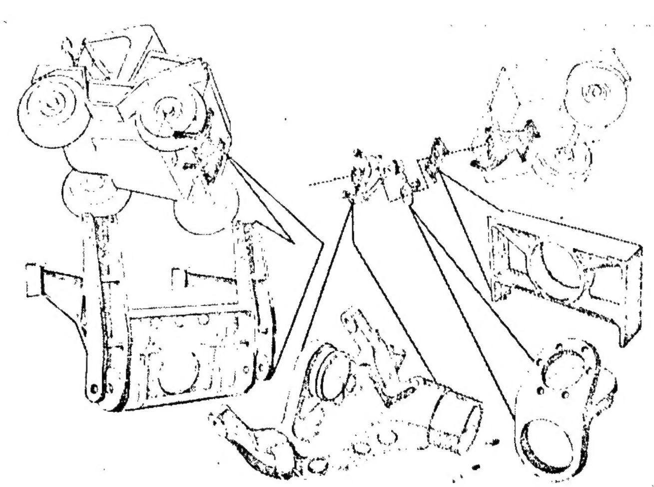

Fig. 6 - XM561 articulation system

tually any type of rough terrain. Fig. 7 illustrates the various attitudes that the vehicle may achieve without compromise to uniform ground contact or tractive effort.

Another unique design feature of the XM561 which is a secondary result of the articulation system refers to the lockout truss (Fig. 8). The lockout truss serves two functions. It transforms the vehicle into a rigid unit for airdrop, and, of equal importance, it provides a "get home" capability of the vehicle in the event of tire failure without benefit of a spare tire. If a tire failure occurs at the center axle, the lockout truss is installed between the tractor and carrier, and a strut is installed between the tractor body and the center axle assembly to unload one wheel. This essentially transforms the vehicle from an articulating 6 x 6 into a rigid 5 x 5 which is operable, but with appreciable compromise to mobility. If a tire failure occurs at a location on the vehicle other than the center axle, this tire and wheel must be replaced by a tire and wheel from the center axle.

MOBILITY EVALUATION

To evaluate the overall mobility of the XM561, it is necessary to consider the two basic factors which are predominant. The first are the conventional criteria which can be used to evaluate, by mathematical analysis, the behavior of a wheeled vehicle in soil having certain physical characteristics and moisture contents.

The first set of factors relate to the vehicle itself and include tractive effort, approach and departure angles, ground clearance, ground pressure, number of axles, and tire size. The second set of factors to be considered relate to the soil and include soil sinkage, contact area, compaction resistance, bulldozing resistance, and soil moisture content.

A mobility comparison was conducted by the U.S. Army Tank-Automotive Center Land Locomotion Laboratory, whereby soil properties, wheel loads, and tire size were evaluated, and the drawbar performance of the XM561 was determined based on the calculated forces acting on the soil /tire interface. Similar mathematical analyses were made for the M35 (2-1/2 ton 6 x 6) and the M37, (3/4-ton, 4 x 4).

The data obtained were plotted on soft soil performance curves as shown in Fig. 9. These curves plot the drawbar pull/weight ratio against a soil consistency value K. The soil consistency K may vary from 1 to 8, through a range of approximately 14-24% moisture content. As shown on the graph, the K value is inverse to the moisture content. Also, the values represented are based on what is considered to be a typical Michigan form soil.

The soft soil performance curves are basic and directly affect the second basic mobility factor of the XM561, namely the articulation system, and the vehicle's independent suspension. In the negotiation of muddy terrain having a high moisture content, the XM561 shows an increase in drawbar pull/weight ratio of approximately 200% at a point where the comparative vehicles would be immobilized (bellied out), to an increase of 30% in a soil having less moisture content (approximately 14%).

This means that, within this range, additional tractive effort is available to impart greater mobility in four areas, namely, to overcome obstacles in rough terrain, to provide greater maneuverability and agility, to improve slope performance in muddy terrain, and to tow trailed loads.

In support of the preceding, the Aberdeen Proving Ground, the Army's vehicle test and evaluation center, conducted a mobility evaluation of the three comparative vehicles used in the mathematical analysis. This mobility evaluation of the XM561 was conducted with a standard M37 and M35A1 truck for comparison. Tire pressures were adjusted to 12 psi on the XM561 and 15 psi on the M37 and M35A1. Four general test areas were utilized to obtain a variety of adverse soil types. These areas included Churchville Mud Slopes (cohesive loam soil), Munson Hogwallow (sandy loam soil), Munson Sand Course (tilled beach sand), and Wirsing Swamp Area (virgin swamp and tilled swamp mud). The M35A1,

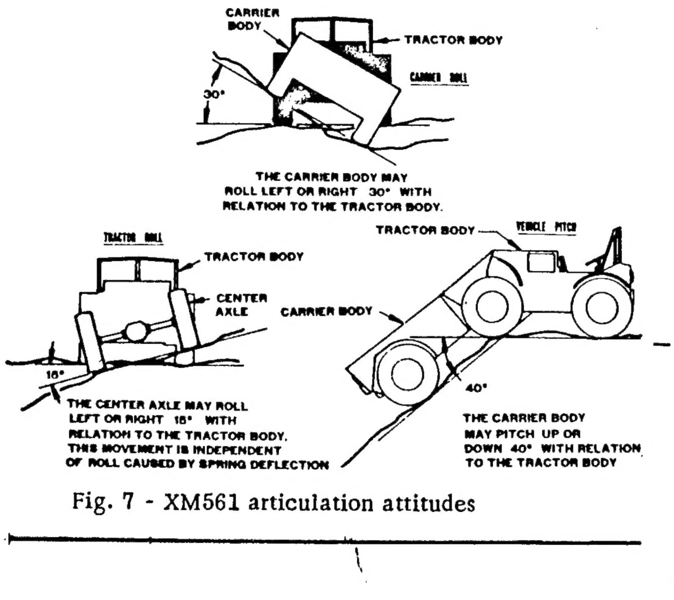

Fig. 7 - XM561 articulation attitudes

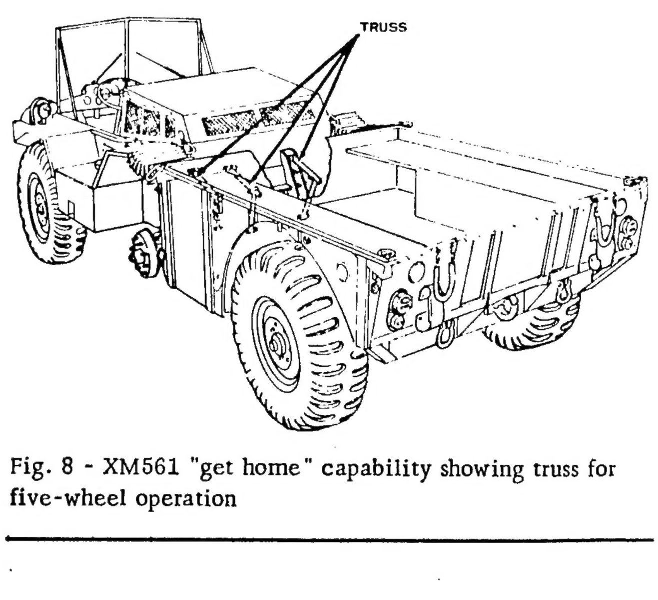

Fig. 8 - XM561 "get home" capability showing truss for five-wheel operation

2-1/2 ton, 6 x 6 cargo truck was included only for drawbar pull comparison on the Munson Sand Course.

Test results from the four adverse soil/terrain areas revealed the following:

Churchville Mud Slopes - Measurements were made for vehicle speed and wheel slip of both the XM561 and the M37 over a wheel penetration range of 4-12 in. in cohesive loam soil. Performance characteristics of the XM561 exceeded those of the M37 at all penetrations exceeding 4 in.

Munson Hogwallow - Operation in the sandy loam soil of the Hogwallow was inconclusive in that both the XM561 and M37 became immobilized at a penetration of approximately 13 in. and a soil moisture content of approximately 21%. At a 10 in. penetration and soil moisture content of 20%, both vehicles negotiated the course but at extremely high wheel slip and low vehicle speeds. The major variation between the two conditions was the depth to which the soil was tilled.

Munson Sand Course - During this test, the drawbar pull characteristics of the XM561, M37, and M35A1 cargo trucks were evaluated while operating in sand tilled to a depth of 14 in. Moisture content ranged from 8-10%. Drawbar pull of the XM561 and M35A1 were comparatively equal (average 2090 lb) over a wheel slip range of 30-90%. The M37 developed approximately 790 lb drawbar pull, or 38% of that obtained by the XM561. Based on the drawbar pull in terms of per cent of gross vehicle weight, the XM561 developed twice that of the M37 or the M35A1.

Wirsing Swamp Area - This area consisted of three types of swampy terrain. One area was disked to a depth of approximately 12 in. and had a moisture content of approximately 43%. The second area was virgin swamp with a thick undergrowth. The third area was a fluid, bottomless swamp with some swamp grass and several partially rotted stumps and logs. The M37 made two passes through the area with thick undergrowth, but became immobilized on the third pass when the undergrowth penetrated. In the tilled and fluid swamp areas, the M37 was immobilized within two vehicle lengths. The XM561 negotiated all three areas with comparative ease.

As a result of the data obtained on drawbar pull, wheel slip, road speed, wheel penetration, and soil moisture content, the test under adverse soil conditions revealed that the mobility performance of the XM561 was superior to that of the M37 cargo truck in all areas tested. The XM561 demonstrated improved tractive effort over current wheeled vehicles of near equal payload classification in virgin hill terrain, soft muddy soil, swampy areas, and dry sand.

In comparing the XM561 with tracked vehicles such as the Armored Personnel Carrier, M113, and Amphibious Cargo Carrier, M116, the mobility of the tracked vehicles due to the lower ground pressure was superior in extremely soft muddy soil. However, the ability of the XM561 to negotiate obstacles such as ditches, banks, rocky inclines, and adverse soil conditions was considered exceptionally good. The factors which contributed to this capability were the articulation system, the independent suspension, and the limited slip differentials. The XM561 was generally equivalent to the tracked vehicles on severly rough undulating terrain, and superior with respect to driver riding and handling characteristics.

SUMMARY

The XM561 cargo truck has indicated that an articulated vehicle design is an advancement in the state-of-the-art and will provide the recognized military need for a signif-

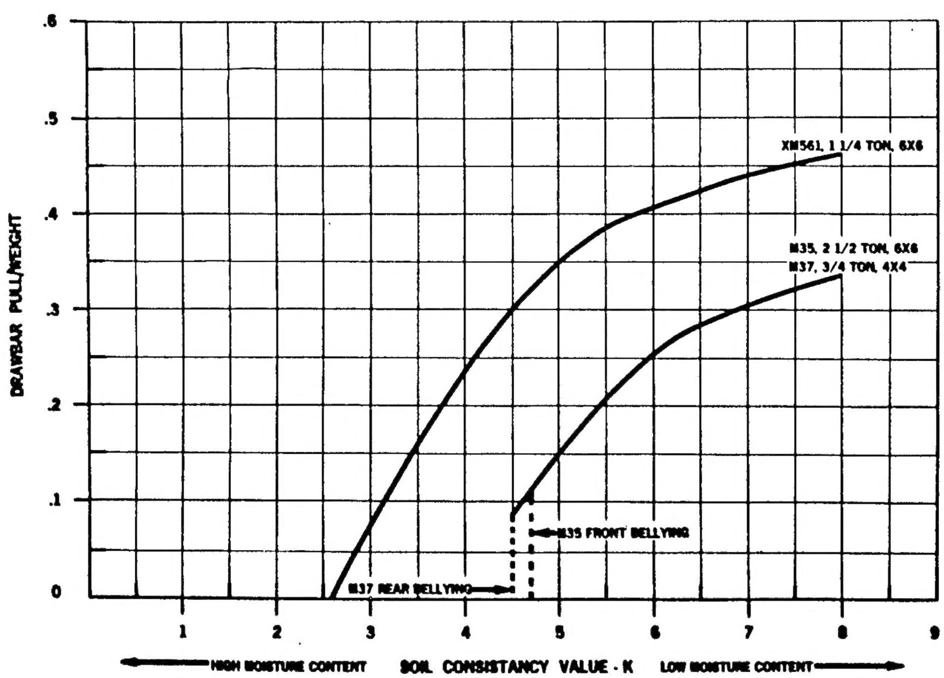

Fig. 9 - Soft soil performance of XM561, M35, and M37

icant improvement in ground mobility. Despite limited testing the XM561 has already proved to be superior to its wheeled vehicle predecessors, and in some instances (rider comfort, handling, and highway performance) is superior to tracked vehicles.

The XM561 design is based on the Army's concept to attain improvement in vehicle durability and reliability, ease of maintenance, fuel consumption and operating economy, producibility, and parts interchangeability, as well as performance. These requirements are imperative to reduce the logistic burden during wartime operations.

Extensive engineering and service tests of 12 pilot vehicles, as well as numerous modification kits which qualify its stature as a general purpose vehicle, will establish the XM561 with regard to mobility. Teh evaluation of other requirements imposed by the Army (durability and reliability, ease of maintenance, fuel consumption, etc.) will determine its acceptance as a standard type.

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